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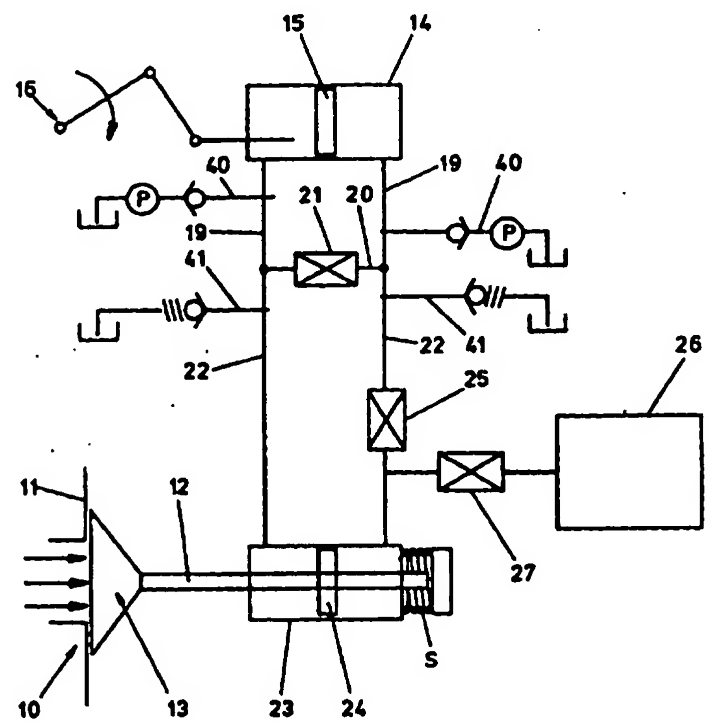
(57) Abstract

A hydraulic actuator (10) which controls the operation of a cylinder valve having a valve seat (11), and a valve element (12) which is linearly reciprocable between open and closed positions with respect to valve seat (11), a valve seal housed in the closing face of valve head (13), (or a part of the valve seat (11) engaged by head (13)), a valve operator connected to the valve element (12) and operable in a release mode to move the valve element away from its valve seat and in a valve-closing mode to move the valve element towards its valve seat, and a hydraulic actuator circuit (19, 22) communicating with the valve operator and operable to apply a closing motion to the valve element (12) via the valve operator which reduces in speed as the valve element (12) moves towards the valve seat (11) and engages with the valve seal. The hydraulic actuator is particularly suitable for controlling the operation of a cylinder valve of a positive displacement type compressor having "soft" seals, although it does have general application to hydraulic actuation of cylinder valves of other types of engine having valve controlled fluid pressure chambers which are filled, pressurised and then discharge pressure fluid in repeated cylces of operation.



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HYDRAULICALLY OPERATED ACTUATOR

This invention relates to a hydraulically operated actuator for controlling the reciprocation e.g. angular and/or linear of a working element, such as the actuating stem of a valve, and is particularly, though not exclusively concerned with the hydraulic actuation of inlet and exhaust valves of positive displacement type air compressors (linearly displaceable piston type air compressors). It should be understood, however, that the invention is not restricted to such use, and may be applied to the hydraulic actuation of other types of valve controlled pressure chambers which are filled with a fluid medium which is then pressurised, and exhausted, in repeated cycles of operation; or to the control of a reciprocating working element, such as a punch, stamp or forging device.

Modern air compressors have of late been almost exclusively of the rotary, mainly screw (or centrifugal for large outputs) type. This is because piston compressors, although having higher efficiencies during compression, but more especially during unloaded running, need much more maintenance. One area of such maintenance is the valves. Valves on practical compressors are always air pressure operated steel diaphragm types, with harsh mechanical opening and closing characteristics, with the dynamics of the movements of the mechanical elements being largely uncontrolled. The stress and wear of the valves which this gives rise to is the main reason for having to change valves frequently.

In order to make piston type compressors, with all their intrinsic advantages again competitive, it is proposed to replace the pressure operated valves with controlled motion valves, such as are used, for example, on most heat engines, whether internal combustion or steam.

In the operation of a positive displacement type of air compressor, a piston is driven back and forth within a cylinder at relatively low speed, and inlet and outlet valves are operated in timed sequence with the movement of the piston so

as to control (1) the induction of a charge of air (2) compression of the charge and (3) discharge of the compressed charge in a repeated cycle of operations.

The inlet valve is normally held open throughout the major part of the induction stroke of the piston, and is held closed against its valve seat during the compression and discharge stroke of the piston, whereas the exhaust valve is normally held closed against its valve seat during the induction stroke and also the major part of the compression stroke, and is only held open for a short time interval at or near the end of the compression stroke to allow the compressed charge to be discharged.

Often, positive displacement compressors are of the double acting type, so that each side of the piston can carry out its own cycle of operation with respect to the air chamber defined within the cylinder between that piston side and the facing end of the cylinder, and corresponding inlet and outlet valves are provided to control the air chambers defined on each side of the piston.

Each valve is movable towards and away from the respective valve seat as it moves between the open and closed position, and in some applications it is desirable to provide some form of resiliently deformable seal which is engaged by the valve as it moves to the closed position. In order for the seal to have a useful life, it is desirable to provide some means of actuation of each valve which minimises the impact of the closing force of the valve on the respective seal.

Accordingly, in one aspect of the invention, there is provided a hydraulic actuator for a cylinder valve and which comprises:

a cyclic hydraulic flow generator for producing repeated cycles of hydraulic flow output in which each cycle has an oscillating waveform;

a master circuit communicable with said generator;

a slave section communicable with said master circuit;

a valve operator communicable with said slave section and connectable to a cylinder valve, said operator being operable

in a release mode to move the valve away from its valve seat and in a valve-closing mode to move the valve towards its valve seat; and,

valve means for controlling the flow of hydraulic fluid in the master circuit and the slave section and operable at predetermined time intervals within each cycle of operation of the generator in order to apply selected samples of the oscillating waveform of the generator output to operate the valve operator in at least one of its modes of operation.

When, as is preferred, there is a requirement for a valve closing speed which reduces as the valve approaches and then engages its valve seat, the selected sample of the oscillating waveform of the generator output will be taken from a portion of the waveform in which the flow is reducing i.e. in a portion of the waveform between a peak and a succeeding trough.

In a positive displacement compressor, which for preference is provided with soft seals, and packings for the inlet and exhaust valves, it can therefore be arranged that each valve makes a relatively gentle engagement with its seal as it completes its closing movement, and this will enhance the working life of such seals and reduce maintenance costs.

The invention is not, however, restricted to use either in a positive displacement type compressor having soft seals, or indeed in a positive displacement compressor as such, but has general application to hydraulic actuation of cylinder valves of other types of engine (pumps or motors) having valve controlled fluid pressure chambers which are filled, pressurised and then discharge pressure fluid in repeated cycles of operation.

According to a second aspect of the invention, there is provided a hydraulically actuated cylinder valve which comprises:

a valve seat;

a linearly reciprocable valve element movable between open and closed positions with respect to the valve seat;

a valve operator connected to the valve element and operable in a release mode to move the valve element away from

its valve seat and in a valve-closing mode to move the valve element towards its valve seat; and,

a hydraulic actuator circuit communicable with said valve operator and operable to apply or permit a closing motion of the valve element via the valve operator which reduces in speed as the valve element moves towards the valve seat and engages with the valve seat.

A valve seal may be provided which comprises a resiliently deformable seal which may be an O-ring or other soft packing, and which may be housed in the closing face of the valve element, or in the portion of the valve seat engageable by a head of the valve element.

According to a third aspect of the invention there is provided a linearly reciprocating piston type compressor which comprises a cylinder, a floating piston mounted for linear reciprocation in said cylinder, a piston rod coupled with said piston and guided so as to control the reciprocating movement of the piston in said cylinder so as to be substantially without direct metal to metal contact with the internal wall of the cylinder, at least one cylinder valve for controlling the admission, or exhaust, of gas relative to the cylinder, a valve seat co-operable with said cylinder valve, a hydraulically operated actuator coupled with said cylinder valve and control means controlling the operator of the actuator so that it is operable to move the valve towards its valve seat, in sequence with the reciprocation of the piston, and with a speed which reduces as the valve approaches and then engages the valve seat.

However, this invention is not restricted to use in controlling at least part of the linear movement of a reciprocating working element e.g. in the form of a valve actuator stem which is just one preferred use, but may be applied to control the reciprocating movement of other working elements, such as stamps, punches and forging devices.

Accordingly, in a still further aspect of the invention, there is provided a hydraulically controlled actuator for controlling the reciprocation of a working element, said

element being moveable in one direction in a working mode and in an opposite direction in a release mode, and in which the actuator comprises:

a cyclic hydraulic flow generator for producing repeated cycles of hydraulic flow output in which each cycle has an oscillating wave form;

a master circuit communicable with said generator;

a slave section communicable with said master circuit;

an operator communicable with said slave section and connectable to said working element, said operator being moveable in one direction to operate the working element in one of its modes and being moveable in an opposite direction to operate the working element in the other of its modes; and

valve means for controlling the flow of hydraulic fluid in the master circuit and the slave section and operable at predetermined time intervals in order to apply selected samples of the oscillating waveform of the generator output to operate said operator, whereby said operator can cause or allow the working element to operate in at least one of its modes of operation.

The valve means may be arranged to select any suitable samples of the oscillating waveform of the generator output, and in which each selected sample may be taken from more than one cycle of operation of the generator. Alternatively, a selected sample may be taken from a portion of each cycle of operation of the generator.

The hydraulically controlled actuator according to this still further aspect of the invention may be utilised to control the linear (or angular) reciprocation of many different types of working element, such as the working element of a punch, stamp or forging device. The hydraulic circuit may be designed to provide any required linear speed/displacement profile of the reciprocating working element, to provide any required characteristics e.g. to provide any required acceleration/deceleration of the working element as it approaches a workpiece, or as it moves away from working engagement with the workpiece.

Preferred embodiments of the invention will now be described in detail, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic illustration of a hydraulic actuator circuit for a cylinder valve according to the invention;

Figure 1a is a detail of an alternative arrangement of part of the circuit shown in Figure 1;

Figure 2 is a series of graphs showing the operating cycles of the component parts of the circuit shown in Figure 1;

Figure 3 is a schematic illustration of a further circuit arrangement; and

Figure 4 is a schematic illustration of a still further actuator circuit arrangement according to the invention.

Referring now to Figure 1 of the drawings, there will be described a hydraulic actuator circuit to control the opening and closing movements of inlet and exhaust valves of a positive displacement type air compressor, by way of example only.

However, it should be understood that the invention has general application to the control of the linear movement of a reciprocating working element, and so as to provide any required profile of an acceleration/displacement graph and especially those parts of the graph corresponding to engagement with, and separation from a workpiece.

Figure 1 shows a hydraulic actuator circuit for a cylinder valve, which can be the inlet valve or the exhaust valve, and Figure 2 shows cycles of operation of the inlet and exhaust valves.

The hydraulic actuator shown in Figure 1 is intended to operate a cylinder valve, shown schematically by reference 10, and which comprises a valve seat 11, and a valve element 12 which is linearly reciprocable between open and closed positions with respect to valve seat 11, element 12 having a valve head 13 which is engageable with valve seat 11 when in the closed position. Although not shown, a resiliently deformable valve seal may be provided, which may take the form

of an O-ring or soft packing, and which is housed either in the closing face of head 13, or in a part of the valve seat 11 engaged by the head 13.

The hydraulic actuator, which controls the linear reciprocation of valve element 12, will now be described in detail. The actuator comprises a cyclic hydraulic motion generator for producing repeated cycles of hydraulic flow output having an oscillating waveform, and in the schematic illustration comprises a master cylinder 14 having a piston 15 which is driven back and forth within cylinder 14 under the action of a rotary crank mechanism 16. The crank mechanism 16 will rotate in an (integral) proportional relationship to the operation of the cylinder whose valves are to be controlled, so that the inlet and exhaust valves can be operated at required time intervals during the induction, compression and exhaust stages of the air compressor i.e. for two revolutions of the compressor input, there will be a whole number of revolutions of master crank mechanism 16.

Each cycle of operation of the hydraulic flow generator has an integral number of peaks and troughs per compressor cycle, and in the illustrated arrangement has six peaks and troughs of a sinusoidal waveform, as can be seen at graphs b and c in Figure 2. However, other shapes of waveform may be suitable i.e. not necessarily sinusoidal and input drive to obtain the required waveform may take other forms e.g. a rotary cam drive.

Graph 2a shows a graph of movement of piston 17 of compressor cylinder 18 and the selected intervals of operation of the inlet and exhaust valves during each cycle of operation of the compressor. Thus, Figure 2a shows that the suction valve is closed from the "bottom dead centre" of the compressor 18 for 180° until it reaches "top dead centre". It should be appreciated that in practice it will be allowed to remain closed for a little time longer to allow the retreating piston 17 to decompress trapped air to atmospheric pressure before opening.

The master cylinder 14 of the cyclic motion generator is

communicable with a master circuit 19 having flow and return lines which communicate with opposite ends of the master cylinder 14, and which include a valve-controlled bridging line 20 provided with a diverter valve 21 whose operation between open and closed positions is controlled as part of the operating sequence of the hydraulic actuator, as will be discussed in more detail below.

A slave section 22 is communicable with master circuit 19, and is connected to opposite ends of a slave cylinder 23 having actuator piston 24 coupled with the valve stem of valve element 12, and which thereby forms a valve operator which is operable in a release mode to move the valve element 12 away from valve seat 11, and in a valve-closing mode to move the valve element 12 towards the valve seat 11.

Slave section 22, together with diverter valve 21 in master circuit 19, forms jointly a "valve means" for controlling the flow of hydraulic fluid in the master circuit 19 and the slave section 22 and operable at predetermined time intervals within each cycle of operation of the motion generator (master cylinder 14) in order to apply selected samples of the oscillating waveform of the generator output to operate the valve operator (23, 24) in both modes of operation.

The operation of the valve means (21) is controlled in such a way that the closing speed applied to the stem of the valve element 12 reduces as the head 13 approaches and then moves into engagement with the valve seat 11 i.e. at or near the end of the closing stroke of movement. This minimises valve seat and valve wear and bearing in mind that this may be direct metal to metal contact, this will reduce noise and minimise metal fatigue and "pitting". However, even in the case of use of resiliently deformable seals and soft packings, this enhances seal life, and therefore reduces maintenance costs.

When the suction valve, for instance (for maintenance, unloading or safety purposes) is on the outside, then a discrete force to resist the air pressure is needed during the compression strokes. Similarly, the exhaust valve may also

need locking down if premature opening is not desired.

Therefore, while the master circuit 19 and slave section 22, under control of the valve 21, and also of control valve 25, provide controlled application of selected portions only of the oscillating waveform produced by the master cylinder 14, in order to move the valve element 12 towards and away from the closed position, preferably a separate hydraulic pressure device is provided to maintain the valve element "locked" in the closed position when it has been moved to that position. Therefore, a high pressure source 26 is provided which is communicable with the slave section 22 via control valve 27, to apply a constant biasing force to piston 24 after the latter has been moved to the left upon completion of a closing movement under the control of valves 21 and 25 of the master circuit 19 and slave section 22. The sequence of operation of valves 21, 25 and 27, for a typical cycle of operation will be described in more detail below.

Assuming that the valve element 12 is the inlet or suction valve, Figure 2b shows the oscillating waveform produced by the suction valve master cylinder, and Figure 2a shows the time intervals, during a cycle of operation, in which the suction valve carries out opening movement, as shown by the relatively short section 28 of the graph, and by longer section 29 in which the valve is maintained open (preferably by means of a small spring biasing force), followed by short section 30 in which valve closing movement takes place, followed by further longer section 31 in which the valve remains closed.

Figure 2b shows the oscillating waveform of the suction valve master cylinder, and the two marked samples of this waveform, shown by references 32 comprise short duration predetermined time intervals at which diverter valve 21 is closed, in order to initiate suction valve opening at section 28 and suction valve closing shown by reference 30 in Figure 2a.

While the diverter valve is open, the suction valve dwells (either closed or open) along lines 39 and 40 while the waveforms are being short-circuited or by-passed.

Figure 2c shows the oscillating (sinusoidal) waveform generated by the exhaust valve master, and very short predetermined selected sample of this waveform shown by reference 33 is the interval at which the diverter valve 21 of the exhaust valve master circuit is closed, it being understood that inlet valve master circuit has its own diverter valve 21 operated at predetermined short term intervals 32 described above with reference to Figure 2b.

Upon closure of the diverter valve associated with the exhaust valve at section 33, the exhaust valve is caused to open and close at the final portion of the compression stroke of piston 17 to allow the compressed charge of air to be discharged, this final section being shown by reference 34 in Figure 2a.

As can be seen from Figure 2b, in respect of the second predetermined interval 32 at which the diverter valve (21) associated with the inlet master circuit is operated, the inlet master waveform is moving from the peak value shown by reference 35 to the succeeding trough shown by reference 36, and therefore the closing speed applied to valve element 12 will reduce as it approaches and then moves into engagement with the valve seat 11.

Similarly, the closing speed applied to the exhaust valve also takes place while the exhaust master waveform is moving from peak 37 to trough 38 shown in Figure 2c.

There will now be described typical cycle of operation in respect of either valve element:

1. With the control valve 25 of slave section 22 open, and control valve 27 closed, the following operations can take place:

(a) with the diverter valve 21 closed (and this may be a simple open / close valve), the (piston 24) of slave cylinder 23 reciprocates to move the valve element 12;

(b) with the diverter valve 21 open, fluid in the master circuit 19 "short circuits" or bypasses the slave section 22, whereby the valve element remains at rest.

2. With the diverter valve 21 open, the control valve 25

closed, and control valve 27 open;

the valve element is held pressed to the left against the valve seat 11, so that the air valve cannot open.

The diverter valve 21 is only closed when valve 25 is open and control valve 27 closed, so that the piston 24 can move. The high pressure from source 26 is used to keep the suction air valve closed during the compression stroke when, as is preferred, the air valve is located on top of the cylinder end plate which is convenient for some applications.

The master circuit and slave section described so far with reference to Figure 1 will be provided with replenishment lines and pressure relief lines, as shown schematically by reference 40 and 41 for the replenishment lines and relief lines respectively, and coupled with the master circuit 19, and operating in a manner which will be well known to those of ordinary skill in the art.

Figure 1 provides an arrangement for controlling the movement of actuator piston 24, and an alternative arrangement for diverter valve 21 is shown in Figure 1a, and as designated by reference 21a. The valve 21a has an unload portion a, a dwell or by-pass portion b, and an actuating portion c as shown. However, while the master waveforms are being short circuited, the slave section is locked in position, rather than being free to move as would be possible in the case of valve 21 in the Figure 1 arrangement.

In both cases, i.e. Figure 1 and Figure 1a, if either valve 21 is permanently open, or the valve of 21a Figure 1a is in position a, valve head 13 is free to move when acted on by external forces and can then be unloaded if e.g. biasing spring S is applied.

If it may be desired to vary the period of the waveform 37 which is generated by the rotary crank mechanism 16, a variable differential drive input may be provided (not shown), which enables variation in the sampled waveform. In addition, other cyclic drive input may be provided e.g. a rotary cam drive.

The control valves which are illustrated schematically

will preferably be electrically controlled valves e.g. solenoid valves.

An alternative circuit arrangement is shown in Figure 3, and in which parts corresponding with those already described are given the same reference numerals. This is a "piggyback" type of arrangement, in which a double piston rod type of actuator has piston rods 1 and 2 of the same diameter, and respective pistons 24 and 24a. (In practice the area of piston 24a is much larger than the area of piston 24, for a purpose which is described subsequently). This is necessary, because otherwise short circuiting would not be possible, in that it would be self-locking.

The piston 24 therefore normally operates the valve element 13 under the control of the actuating circuit, and piston 24a idly follows the movement of piston 24. However, when the valve element 13 reaches the closed position, it can be locked in this position by energisation of the larger area piston 24a via its solenoid or mechanically controlled pressure circuit shown in Figure 3.

An objective of this arrangement is to avoid absorbing an unacceptable amount of energy. To achieve this, the locking piston must travel forwards (to the left in the drawing). Then, when the locking pressure is switched on, it must not allow any more fluid than the compressibility of the fluid in volume 3 allows.

If there were to be locking on area of piston 24 directly, as per the previous examples, then because area of piston 24 has to be small to allow free oil flow in circuit line 19, a very high pressure would be needed, and which would result in unacceptable leakage and compression energy loss. However, the piggyback arrangement shown in Figure 3 overcomes this problem.

The master circuit and slave sections shown in Figure 1 provide a hydraulic actuator arrangement which is effective to operate the valve head 13 in both the valve-closing mode, and the valve-release mode. However, the present invention is concerned with a hydraulic actuator arrangement which is

capable of effecting operation (driving the movement) of a valve head (13) in at least one of its modes (valve-opening or valve-closing), or both modes, according to requirements. In the case of hydraulic driving in one mode only, a separate biasing or control arrangement e.g. a biasing spring may be provided to control the operation in the remaining mode with the hydraulic control being inoperative or rendered ineffective.

A further arrangement of hydraulically operated control means according to the invention is shown in Figure 4, and will now be described in detail. The master cylinder circuit and slave section described above with reference to Figures 1 to 3 comprise arrangements which allow a valve operator to be driven hydraulically in both of its modes of operation i.e. in a valve-closing mode and in a valve-opening mode as required. In the arrangement shown in Figure 1, the slave section comprises a slave circuit, which can apply a hydraulic actuating force to slave piston 24 in either mode of direction. The circuit arrangement shown in Figure 4 includes a slave section i.e. not a complete circuit, and which is effective to drive the valve operator in one direction only. Spring or other biasing is provided to urge the slave piston of the valve actuator in an opposite direction i.e. a valve closing mode, but against the controlled retardation provided by the oil flow out of the actuator (chamber 62) i.e. still giving a "soft landing" on the valve seat. It should be understood, however, that the roles of the slave section and the biasing means may readily be reversed, whereby the slave section can drive the slave piston to move in a valve closing mode, whereas the biasing means is effective to move the slave piston in a valve-opening direction.

Parts corresponding with those already described are given the same reference numerals, and will not be described in detail again. As mentioned above a main difference between the hydraulically controlled valve actuator arrangement of Figure 4, and the previously described embodiments of the invention, resides in the fact that a slave section is provided, rather

than a complete slave circuit. A master circuit is arranged to be pressurised by master piston 15, and is designated generally by reference 50, and includes a pressure line 51 which communicates at one end with one end of cylinder 14, on one side of piston 15, and at its other end with an opposite end chamber of cylinder 14 and on the opposite side of piston 15. Pressure line 51 will transmit hydraulic fluid under pressure under the actuation of piston 15 in similar manner to that described above with reference to Figure 1, but its effect on the actuation of the valve operator is via a solenoid controlled valve 52 and a slave section or line 53 which extends between suitable outlet of a housing of the valve 52 and an inlet 54 in the housing 55 a of a piston and cylinder type of valve actuator which controls the reciprocation of valve operating stem 55. As shown, stem 55 has a valve head 56 which is located internally of compressor cylinder 57 having "floating" piston 58 mounted for linear reciprocation therein, substantially without metal-to-metal contact with the internal wall of cylinder 57 by reason of guidance of piston rod 59, in similar manner to that already described for the previous arrangement.

A biasing arrangement is provided to apply valve-closing movement to valve stem 55, and in the illustrated arrangement comprises a compression spring 60 housed within cylinder 55a and reacting against valve-operating piston 61. Application of hydraulic pressure to chamber 62 in cylinder 55 i.e. the chamber defined on the opposite side of piston 61 to spring 60, will cause piston 61 to move to the left, as shown in Figure 4, in order to lift off the valve head 56 from valve seat 63 i.e. to drive the actuator in the release mode. However, in the actuation mode under the action of spring 60, there will be controlled retardation by reason of the controlled outflow of oil from chamber 62, whereby a "soft landing" on the valve seat can be obtained.

Figure 4 therefore shows an embodiment of the invention in which a slave section can be used, when pressurised by master cylinder circuit 50 via appropriate actuation of valve

52, to move the valve operator in a valve-opening direction. The valve 52 will be operated under the action of its solenoid, and actuator cylinder 14 will be replenished, or altered to overflow in conjunction with a pressure controlled replenishing system (accumulator) 64.

As an alternative to the arrangement shown in Figure 4, it should be understood that the roles of hydraulic pressure actuation/spring biasing, can be reversed, whereby spring or other biasing applies valve-opening movement (under hydraulically controlled retardation), whereas supply of hydraulic pressure to the actuator drives the valve in a closing direction, and this results in a controlled slowing-down of the speed of the valve head as it approaches the valve seat, again to provide a "gentle" closing engagement and impact with the valve seat.

Although not shown, a locking facility may be provided, generally similar to that described above for the other circuit arrangement, when the valve head is on the outside of the compressor.

It should be understood that the above description of preferred embodiments refers to a hydraulically controlled actuator which controls the linear reciprocation of a valve stem, but that the invention may be applied to control the reciprocation of other types of working element. These other possible uses are not shown in the drawings, but will involve control being applied to the reciprocation e.g. linear and/or angular of an operator which is coupled in any convenient manner with the working element concerned.

The hydraulic circuit and the component parts thereof will be designed so that any required profile of any acceleration/displacement graph can be obtained for the working element concerned, and particularly the parts of the graph corresponding to engagement with, and separation from a workpiece. By way of example only, the required profile at these parts of the graph may comprise rapid acceleration, or deceleration, according to requirements. In some instances, it may desirable for the working element to undergo rapid

acceleration as it comes into contact with the workpiece, whereas in other instances it may desirable for the engaging motion of the working element to be decelerating as it moves into engagement with the workpiece. Similarly, the separating movement of the working element e.g. as it commences its return stroke and moves out of engagement with the workpiece, may be controlled to be rapidly accelerating, or otherwise varied, to suit requirements.

Any of these requirements can readily be met by a hydraulically controlled actuator according to the invention, having a cyclic hydraulic flow generator to produce repeated cycles of hydraulic flow output in which each cycle has an oscillating wave form; a master circuit communicating with the generator; a slave section communicating with the master circuit; an operator communicating with the slave section and connectable in any suitable way to the working element concerned and which operator can be moved in one direction to operate the working element in one mode and in an opposite direction to cause the working element to operate in the other mode; and valve means to control the flow of hydraulic fluid in the master circuit and the slave section and operable at predetermined time intervals to apply selected samples of the oscillating waveform of the generator output to operate the operator so that it can cause, or allow the working element to operate in at least one of its modes of operation.

The selected samples of the oscillating wave form of the generator output may be taken from more than one complete cycle of the wave form, or be a selected sample taken from one cycle, as may be required to provide a required profile of the acceleration/displacement graph of the working element.

CLAIMS

1. A hydraulically controlled actuator for controlling the reciprocation of a working element, said element being moveable in one direction in a working mode and in an opposite direction in a release mode, and said actuator comprising:

a cyclic hydraulic flow generator for producing repeated cycles of hydraulic flow output in which each cycle has an oscillating wave form;

a master circuit communicable with said generator;

a slave section communicable with said master circuit;

an operator communicable with said slave section and adapted to be coupled with said working element, said operator being moveable in one direction to operate the working element in one mode of operation and being moveable in an opposite direction to operate the working element in the other mode of operation; and

valve means for controlling the flow of hydraulic fluid in the master circuit and the slave section and operable at predetermined time intervals in order to apply selected samples of the oscillating wave form of the generator output to operate said operator so that the latter can cause, or allow, the working element to operate in at least one of its modes of operation.

2. An actuator according to Claim 1, in which said operator is arranged to be driven by the slave section in said one direction, and biasing means is provided to move said operator in said opposite direction against controlled retardation provided by said slave section.

3. An actuator according to Claim 1 or 2 in which said operator is linearly reciprocable in order to operate the working element.

4. An actuator according to Claim 1 or 2, in which said operator is angularly reciprocable in order to operate the working element.

5. A hydraulic actuator for a cylinder valve and which comprises:

a cyclic hydraulic flow generator for producing repeated

cycles of hydraulic flow output in which each cycle has an oscillating waveform;

a master circuit communicable with said generator;

a slave section communicable with said master circuit;

a valve operator communicable with said slave section and connectable to a cylinder valve, said operator being operable in a release mode to move the valve away from its valve seat and in a valve-closing mode to move the valve towards its valve seat; and,

valve means for controlling the flow of hydraulic fluid in the master circuit and the slave section and operable at predetermined time intervals within each cycle of operation of the generator in order to apply selected samples of the oscillating waveform of the generator output to operate the valve operator in at least one of its modes of operation.

6. An actuator according to Claim 5, and adapted for a cylinder valve having a requirement for a valve closing speed which reduces as the valve approaches and then engages its valve seat, the arrangement being such that the selected sample of the oscillating waveform of the generator output can be taken from a portion of the waveform in which the flow of hydraulic fluid is reducing at or near the maxima or minima of the waveform.

7. A positive displacement compressor having an actuator according to Claim 6, in which the actuator is arranged to operate its respective valve such that the valve makes a relatively gentle engagement with its seat as it completes its closing movement.

8. A compressor having a cylinder valve controlled by an actuator according to Claim 5 or 6, and having a piston guided to reciprocate within a cylinder other than by engagement with the internal wall of the cylinder.

9. A hydraulically actuated cylinder valve which comprises:

a valve seat;

a linearly reciprocable valve element movable between open and closed positions with respect to the valve seat;

a valve operator connected to the valve element and operable in a release mode to move the valve element away from its valve seat and in a valve-closing mode to move the valve element towards its valve seat; and,

a hydraulic actuator circuit communicable with said valve operator and operable to apply, or permit a closing motion of the valve element via the valve operator which reduces in speed as the valve element moves towards the valve seat and engages with the valve seat.

10. A cylinder valve according to Claim 7, including a valve seal housed in the closing face of the valve element, or in a portion of the valve seat engageable by a head of the valve element.

11. A cylinder valve according to Claim 8, in which the valve seal comprises an O-ring or other soft packing.

12. A linearly reciprocating piston type compressor which comprises a cylinder, a piston mounted for linear reciprocation in said cylinder, at least one cylinder valve for controlling the admission, or exhaust, of gas relative to the cylinder, a valve seat co-operable with said cylinder valve, a hydraulically operated actuator coupled with said cylinder valve, and means controlling the operation of the actuator so that it is operable to move the valve towards its valve seat, in sequence with the reciprocation of the piston, and with a speed which reduces as the valve approaches and then engages the valve seat.

13. A compressor according to Claim 12, in which the hydraulic actuator comprises a cyclic hydraulic flow generator for producing repeated cycles of hydraulic flow output in which each cycle has an oscillating waveform; a master circuit communicable with said generator; a slave section communicable with said master circuit; a valve operator communicable with said valve circuit and connectable to said cylinder valve, said operator being operable in a release mode to move the valve away from its valve seat and in a valve-closing mode to move the valve towards its valve seat; and valve means for controlling the flow of hydraulic fluid in the master circuit

and the slave section and operable at predetermined time intervals within each cycle of operation of the generator in order to apply selected samples of the oscillating waveform of the generator output to operate the valve operator in at least one of its modes of operation.

14. A compressor according to Claim 12 or 13, including a piston rod which is guided so as to control the reciprocating movement of the piston in said cylinder so as to be substantially without direct metal to metal contact between the piston and the internal wall of the cylinder.

15. A hydraulically actuated cylinder valve according to any one of Claims 9 to 11, in which said valve operator comprises a piston and cylinder type actuator.

16. A cylinder valve according to Claim 15, in which said piston and cylinder type actuator includes a cylinder, a piston slidable in said cylinder, and a piston rod coupled with said piston and arranged to apply linear movement to said valve element.

17. A cylinder valve according to Claim 15, in which said piston and cylinder type actuator comprises a first piston and cylinder device to operate the valve element, and a second piston and cylinder device coupled with said first device and operating idly until the valve element is closed by the first device and then being operable to lock the valve element in the closed position.

18. An actuator according to any one of Claims 1 to 6, in which the hydraulic flow generator comprises a mechanically operated piston / cylinder device.

19. An actuator according to Claim 18, in which a crank or cam drive provides input to said hydraulic flow generator.

20. An actuator according to Claim 19, in which a variable differential drive input is coupled with said crank or cam drive to provide variation in the sampled waveform.

21. A reciprocating piston compressor including an actuator according to any one of Claims 18 to 20, and driven in synchronism with the operation of said hydraulic flow generator.

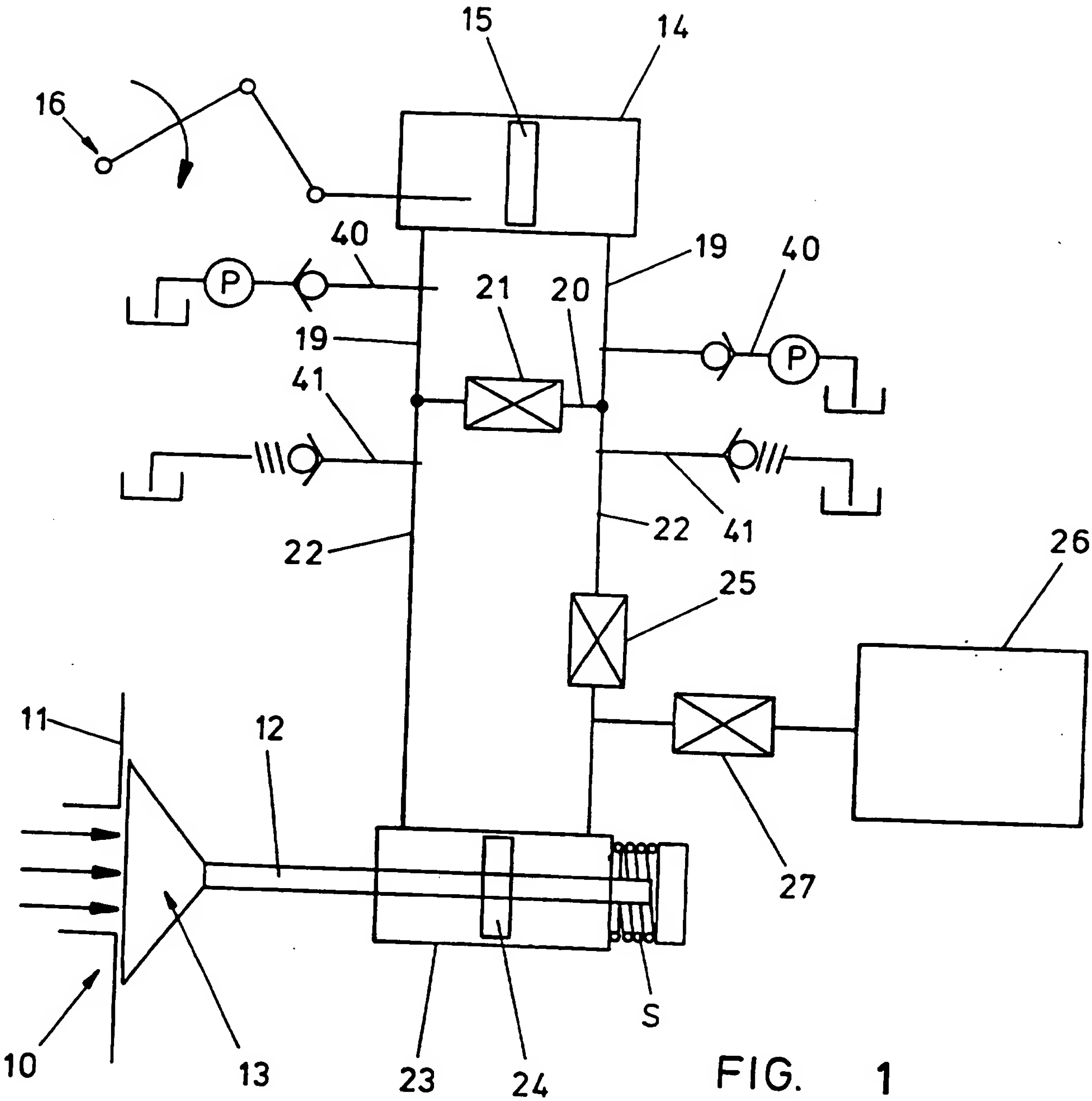
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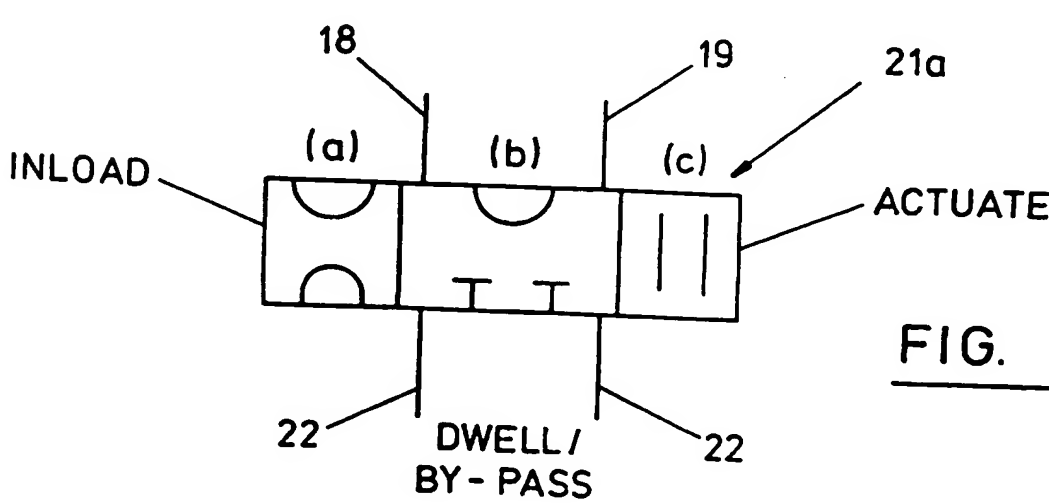
FIG. 1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19
21a
(a)
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(c)
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ACTUATE
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DWELL /
BY - PASS
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FIG. 1a

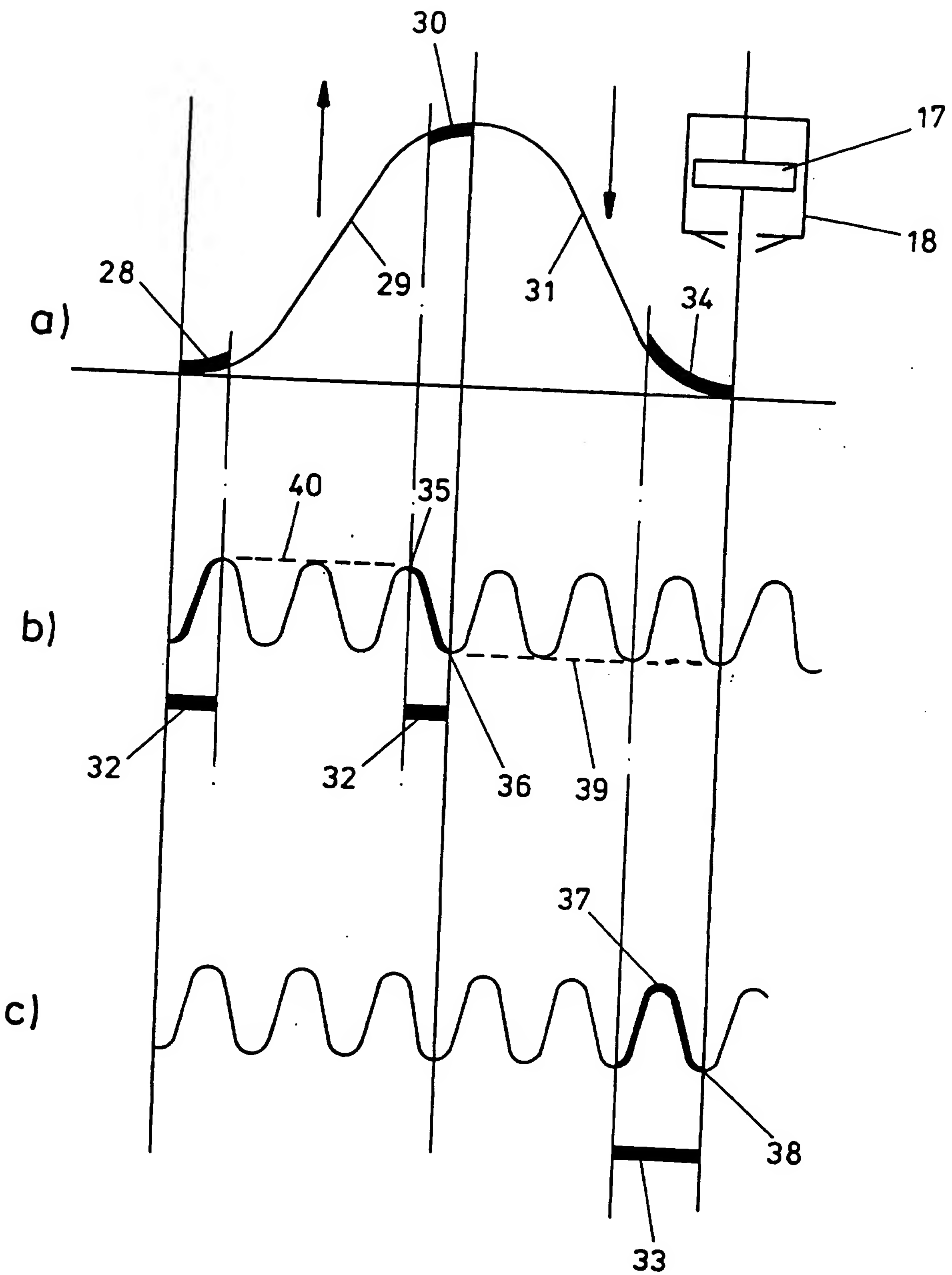

FIG. 2

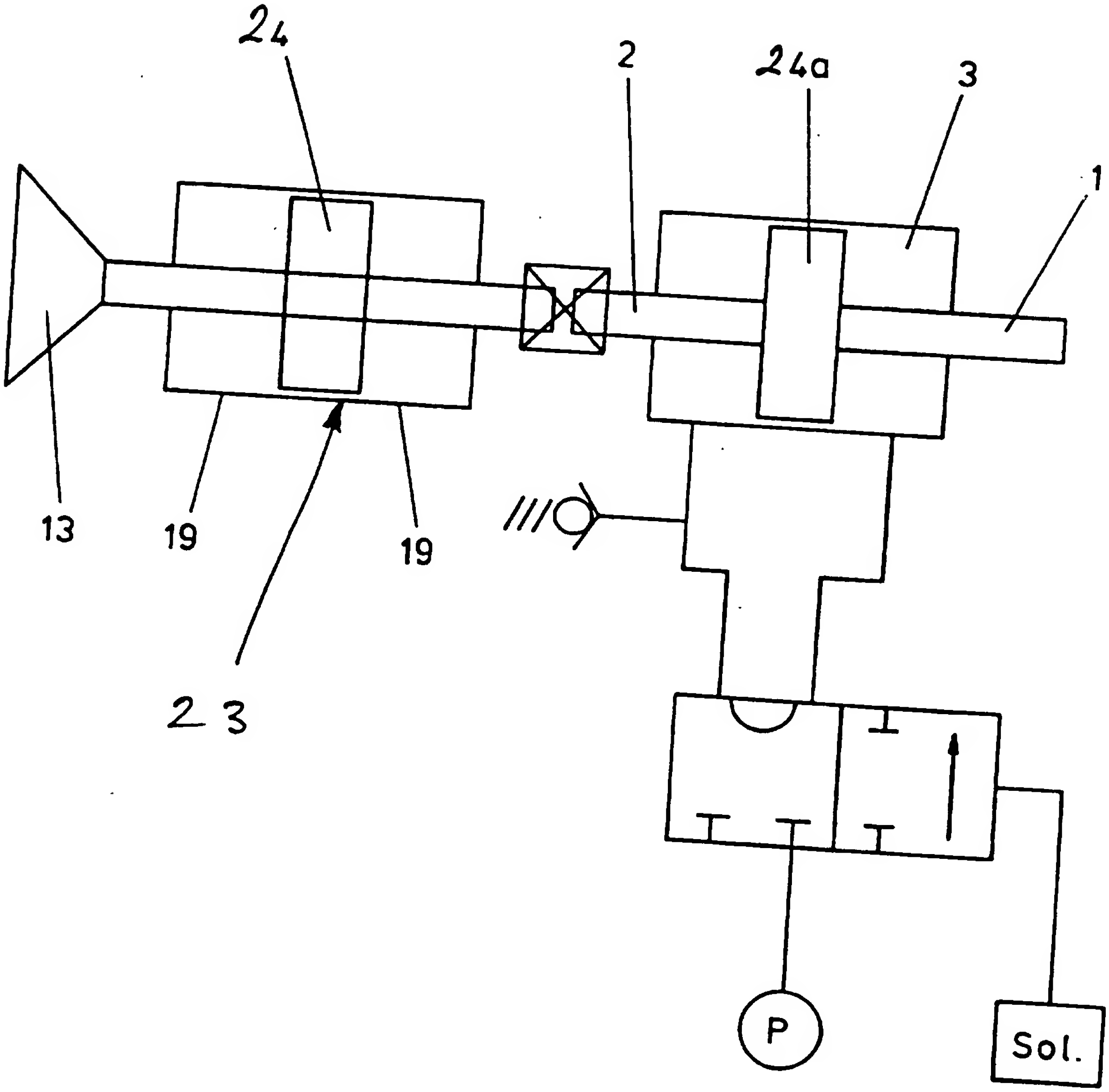

FIG. 3

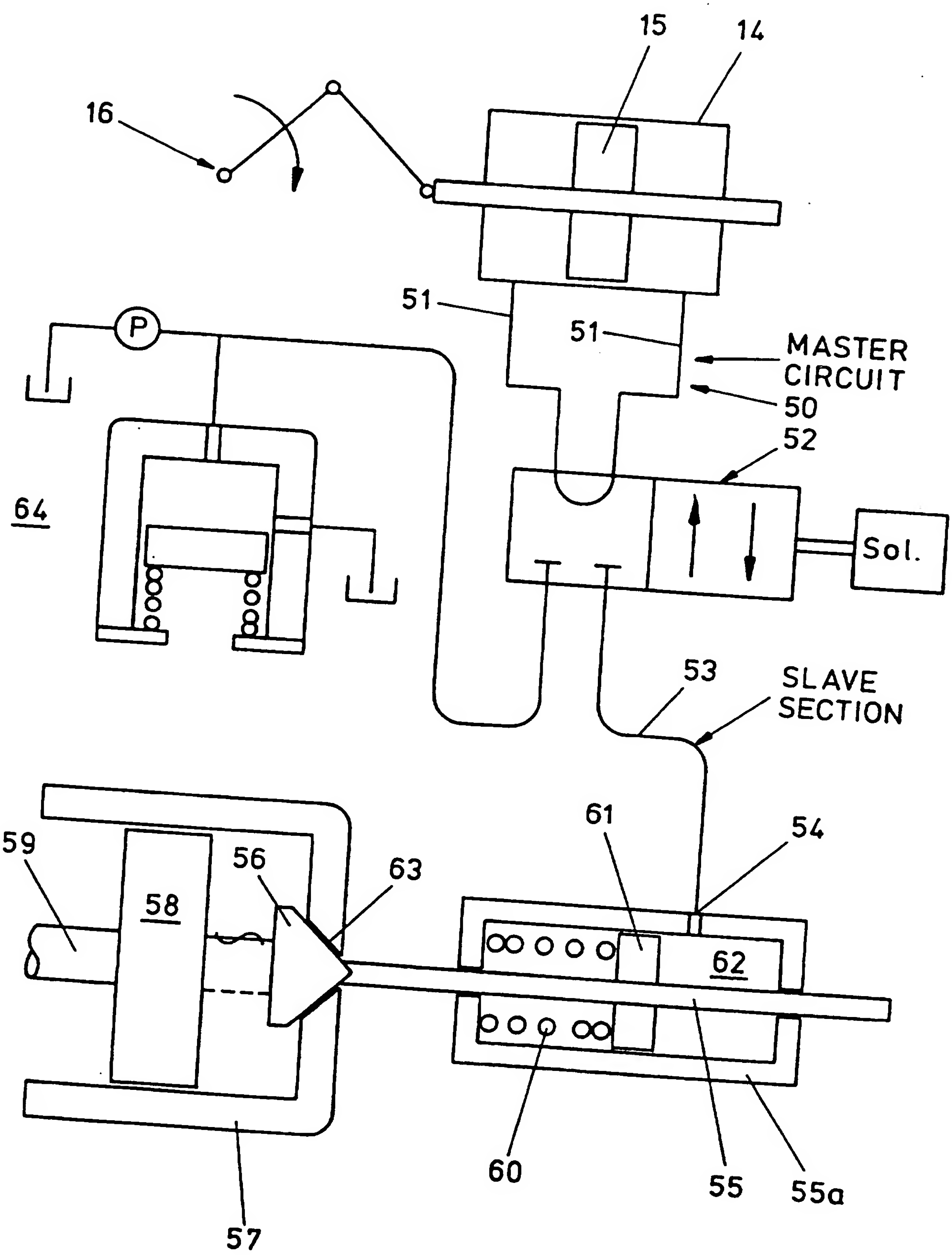
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FIG. 4